

Yukon Waste Vegetable Oil Vehicle Conversion Study

Yukon Government's Energy Solutions Centre

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1 Introduction

In the summer of 2006 the Yukon Government was approached by a Yukon resident interested in examining the viability of operating a vehicle which had been converted to use waste vegetable oil as its primary source of fuel. The Yukon Government's Energy Solutions Centre agreed to provide some financial support for the project in an effort to learn more about the viability and benefits of using this technology in the Yukon's harsh northern climate. Below is a summary of the findings from that study.

1.1 Vegetable Oil as a Source of Fuel

The use of vegetable oil to fuel an engine is not a new concept; Rudolf Diesel patented the invention for what is now called the "diesel engine" in 1898 using peanut oil as a fuel. Today a variety of vegetable oils including canola, peanut, soy, safflower and sunflower are used throughout the world as fuel in conventional diesel engines.

1.2 Vegetable Oil and Biodiesel

The purpose of this study was focused on using unmodified vegetable oil as a transportation fuel; however, it is worth noting that methods exist to chemically treat vegetable oil to convert it to what is commonly referred to as "biodiesel". This fuel can be used in most conventional diesel fuel systems. In this process lye and methanol are used to chemically transform vegetable oil to biodiesel. This chemically treated vegetable oil is generally mixed with regular diesel to improve its cold climate characteristics. However, as stated above, the purpose of this study was to evaluate the efficacy of using unmodified vegetable oil as a transportation fuel in Yukon conditions.

2 Sources of Waste Vegetable Oil

The availability of waste vegetable oil (WVO) for free or at low cost from restaurants and other facilities is a potentially attractive source of vegetable oil for fuel. For the purpose of this project three local Whitehorse restaurants agreed to allow the operator of this system to collect waste vegetable oil (WVO) for free. A collection schedule was established with two restaurants with the third restaurant agreeing to facilitate collection if additional WVO was required in the future.

3 Waste Vegetable Oil Processing

Unlike fresh vegetable oil, WVO must be "processed" before it is placed in a vehicle's fuel system to remove food particles and water. High quality WVO will minimize processing problems and costs, and maximize the amount of usable oil. Good quality WVO will be stored in a sealed container with a minimum of miscellaneous other waste products.

The processing of WVO involves first filtering through at least two separate filters to remove food and other waste particles. The first filter may be a common window screen or similar material which acts to remove large particles. The second filter must trap particles as small as 10 microns. This second filter is often made of common items such as old jeans, panty hose or purchased filter bags.

Water removal from WVO is an essential aspect of the process. Water in diesel engine fuel causes rust to develop in the injector pump and, in sufficient quantities, can cause damage to other parts of the engine. Initial settling (prior to or during the first 2 filter steps) will result in most of the water moving to the bottom of the container; however, suspended water will not settle out unless the WVO is heated and then allowed to settle. Heating breaks the tension that holds the small water drops in suspension, and allows them to settle to the bottom of the container.

4 Waste Vegetable Oil Fuel Delivery Systems

In order for vegetable oil to be usable as a fuel it must be heated before entering the engine's combustion chamber. This ensures the vegetable oil will flow easily through the fuel system and vaporize adequately for efficient combustion within the engine cylinder. There are various methods and kits available on the market designed for this purpose.

In converting a conventional diesel vehicle to use vegetable oil there are two basic types of fuel systems used:

- i. **The single tank system** uses the vehicles existing diesel fuel delivery system to deliver the vegetable oil to the engine. This single tank system requires that either heat be added to the fuel delivery components (tank, fuel lines, filter, etc) or that a large quantity of diesel fuel be added to the vegetable oil so that the overall percentage of vegetable oil is less than 10% of the mixture.
- ii. **The double tank system** consists of the existing diesel fuel delivery system plus a parallel, heated system (an additional tank, fuel lines, filter, heat exchanger, etc.) which is used for the vegetable oil. This arrangement allows the operator to use conventional diesel fuel until the engine is warm enough to heat the vegetable oil. Due to the relatively long and cold winters in the North, it's likely that a double tank system is the best option for northern applications.

The vehicle's tank must be constructed of a material that does not react with vegetable oil. Aluminum or other non-reactive type fuel tank will be required as WVO contact with copper and soft steel (steel barrels, some steel fuel lines, etc.) will facilitate polymerization (breaking down of the vegetable oil in an undesirable way).

In order for the WVO to flow out of the tank the vegetable oil in the tank must be heated. This heating can be facilitated through either an external electric heater or an internal engine coolant heater.

The external electric heating method typically uses an AC oil pan heater plugged in briefly while the vehicle is parked. This requires careful placement of the oil pan heater so as to avoid igniting flammable materials. For operational reasons the use of in-tank electric heaters is not recommended as this type of heating has been found to leave deposits in the fuel system.

Using the engine's coolant to heat the oil commonly relies on an in-tank heater. One commercially available conversion system uses copper coils placed in the tank. Other methods such as coils wrapped around the fuel tank to heat the entire contents are occasionally used; however, extended heating in this way may facilitate unwanted polymerization.

Using the engine's coolant to heat the WVO requires the vehicle to run on diesel fuel until the engine's coolant is warm enough to heat the WVO sufficiently. The engine coolant may be preheated via a block or in-line heater.

In addition to the WVO tank, the WVO fuel lines must also be heated. The following are three options for WVO fuel line heating:

- i. **Encase the line in a 12 volt electric jacket** that warms the WVO as it proceeds through the fuel delivery system;
- ii. **Place an engine coolant line parallel to the WVO fuel line** with both lines encased in an insulated sheath to maximize the heat reaching the line and minimize heat loss to the air, and;
- iii. **Place the WVO fuel line within a coolant hose.** The line-within-hose maximizes the heat transfer to the WVO, does not require the space of a parallel line system and does not require installing a larger alternator to power electric heaters.

The heated WVO line delivers the WVO to a heated fuel filter. Electrically heated filters are necessary for larger trucks only. A coolant heated filter is usually adequate, costs less to purchase, does not burn out and does not place an extra electrical generation load on the engine's alternator. Heating the filter "head" is recommended since use of a coil technique makes changing the filter more difficult.

After passing through the heated filter, the WVO must be heated to approximately 160 F to vaporize properly when injected into the engine. Again the options are electric or engine coolant heating. Both electric jackets and engine coolant heat exchangers are available for this purpose. Since engine coolant is available, its temperature is easier to control and it does not place an extra load on the engine alternator, it is recommended.

After passing through the final heat exchanger, the WVO line merges with the diesel fuel line, prior to the injector pump, this then pressurizes the fuel for delivery to the fuel injectors.

Heating the last section of the fuel line, after the point where the WVO fuel line merges with the diesel fuel line, is not recommended due to the potential for heated diesel fuel providing less lubricity to the engine's moving parts.

5 Waste Vegetable Oil Processing System/Vehicle Conversion Cost

Equipment that can be used to process the WVO prior to placing it in the vehicle's tank consists of some purchased and salvaged items.

The "processing plant" used for this study consists of the following:

		Estimated Cost
1	Plastic garbage bags to transport WVO from restaurant,	\$ 5.00
2	primary filter (salvaged plastic holed bucket with panty hose stretched over bucket top, covered with salvaged metal window screen)	\$ 15.00
3	rigid metal mesh to hold primary filter over plastic garbage can	\$ 10.00
4	plastic garbage can(s) (\$21/can) for primary settling	\$ 42.00
5	salvaged electric water heater	\$ -
6	aluminum garbage can (\$23/can) for holding WVO over wood stove	\$ 23.00
7	40 gallon salvaged plastic barrel for long term storage	\$ -
8	electric heater for immersion in aluminum garbage can to liquefy viscous vegetable oil prior to final filtering and for liquefying WVO in plastic garbage can in winter	\$ 40.00
9	final filter (2 micron particle and water filtering via 12 volt system consisting of pump, filter, hoses made by Golden Fuel Systems	\$ 900.00
10	salvaged 12 volt truck battery for powering final 2 micron filter unit	\$ -
11	salvaged 12 volt battery charger	\$ -
12	large mouth funnel for pouring processed WVO into vehicle WVO tank	\$ 10.00
	Total	\$ 1,045.00

The Frybrid brand vehicle conversion kit used in this study was purchased at a cost of \$1,595 (US) and installed at a cost of \$5,000. Total system cost is approximately \$7,640.

6 Installation of conversion system in vehicle

Manufacturer's estimates for the installation were 16 – 24 hours; however, this number proved to be optimistic for this project likely due to the vehicle's unique characteristics and the local mechanic's inexperience with such a system.

7 Conversion Operations in the Yukon

This conversion appears to have been a success with the vehicle operated for over a year in the Yukon with no major mechanical issues.

For WVO to be used year-round in the Yukon, the delivery system must be capable of heating the oil to a sufficient temperature even when the ambient temperature is -40°C or lower. The example used for this study ran on diesel fuel until an adequate temperature was reached at which time the fuel source was switched over to vegetable oil. In this type of system it is important that the WVO is adequately heated when the system is switched from diesel to WVO, otherwise, cool WVO will be introduced to the injectors, inadequate vaporization will take place, and the engine will either develop damaging cylinder deposits, or simply stop operating.

There are two methods for determining when the WVO is adequately heated:

- i. **a WVO temperature gauge** - This requires the operator to read the gauge to determine when the WVO is hot enough and then to manually switch from diesel to WVO;
- ii. **a microprocessor**, which determines when the WVO is hot enough and automatically switches the fuel source from diesel to WVO

The operator of this vehicle found that bringing the vehicle to operating temperature so as to maximize vegetable oil run time was the key to optimizing the use of WVO and reducing the use of diesel fuel. By partially covering the radiator, covering the front grill, and turning the cabin heater control down, the test vehicle's engine typically reached full operating temperature after approximately 3 kilometers of Yukon winter driving, at which time the vehicle's fuel source could be switched WVO fuel. If a vehicle's heater temperature setting is placed on "hot", engine warming was typically accomplished within 6 kilometres of driving. The appropriate timing for switching to WVO was shown to be dependent on the design of the vehicle coolant and heating system.

The operator of this vehicle found that external ambient air temperatures had limited effect on vehicle warm-up times. The operator found that idling the vehicle with diesel fuel for 3 minutes (4 minutes in the winter) and driving normally for approximately 3 kilometers was adequate to bring the vehicle to a temperature which would allow successful switching of the fuel source to WVO.

Prior to shutting off the engine, the oil in the fuel delivery line (between the WVO tank and the engine) must be purged to prevent cross contamination of fuels. This ensures that the fuel that will feed the engine at subsequent startup is pure diesel fuel. If WVO is in the last section of the fuel delivery line, when the engine is shut off, the engine will not start later due to the viscosity of the unheated vegetable oil. If oil is in the return fuel line

prior to the WVO – diesel return lines' separation point, oil will be delivered to the diesel tank. WVO delivered to the diesel tank will polymerize if it's a steel tank and likely, due to its viscosity, eventually clog the diesel fuel filter.

In the summer, an engine would maintain its temperature for approximately 30 minutes after being shut off, thereby allowing one to avoid purging the system for a short stop at the grocery store. In winter, five minutes of non-operation can be sufficient to cool the engine. In the winter therefore, WVO purging should be done prior to shutting off the engine at any time.

8 Diesel Savings

The following summarize the costs and cost savings associated with this project:

i. Fuel Consumption

Baseline Fuel Consumption (L/ 100 km)	13.64
Conversion Fuel Consumption (L/ 100 km)	6.86
Fuel Consumption Savings (L/ 100 km)	6.78

ii. Project Costs

	Estimated Costs
Processing Plant	\$ 1,045.00
Vehicle Conversion Kit	\$ 1,595.00
Conversion Installation	\$ 5,000.00
Total costs	\$ 7,640.00

iii. Diesel Savings and Payback Period

Average Daily km Traveled	Estimated Daily Fuel Savings (L)	Estimated Annual Fuel Savings (L)	Estimated Annual Dollar Savings ¹	Estimated Payback Period (years)
6	0.4068	148.482	\$ 219.75	34.77
8	0.5424	197.976	\$ 293.00	26.07
10	0.678	247.47	\$ 366.26	20.86
12	0.8136	296.964	\$ 439.51	17.38
14	0.9492	346.458	\$ 512.76	14.90
16	1.0848	395.952	\$ 586.01	13.04
18	1.2204	445.446	\$ 659.26	11.59
20	1.356	494.94	\$ 732.51	10.43
22	1.4916	544.434	\$ 805.76	9.48
24	1.6272	593.928	\$ 879.01	8.69
26	1.7628	643.422	\$ 952.26	8.02
28	1.8984	692.916	\$ 1,025.52	7.45
30	2.034	742.41	\$ 1,098.77	6.95
32	2.1696	791.904	\$ 1,172.02	6.52
34	2.3052	841.398	\$ 1,245.27	6.14
36	2.4408	890.892	\$ 1,318.52	5.79
38	2.5764	940.386	\$ 1,391.77	5.49
40	2.712	989.88	\$ 1,465.02	5.21
42	2.8476	1039.374	\$ 1,538.27	4.97
44	2.9832	1088.868	\$ 1,611.52	4.74
46	3.1188	1138.362	\$ 1,684.78	4.53
48	3.2544	1187.856	\$ 1,758.03	4.35
50	3.39	1237.35	\$ 1,831.28	4.17

During the study period the operator's usual trips ranged from 7 to 40 kilometres with a mean trip being approximately 15 kilometres per day. This use pattern would lead to (approximately) a 14 year payback on the investment in this system.

The cost savings for diesel fuel shown above are based on the data which indicated a diesel fuel use reduction of 49.8%. However, during the course of the study, a number of factors were determined that would likely improve significantly the performance of the vehicle. These are discussed below.

1. The engine warm-up distance could be reduced to less than half in the winter by not turning the van's heater temperature up until after the switch to WVO.
2. Processing difficulties in winter temperatures caused a shortage of WVO fuel and resulted in an excess use of diesel fuel. By having a facility to reliably process WVO, this could be addressed and diesel use could be reduced;
3. An excessive purge time for most of the study period also caused excessive diesel fuel use. Reducing this purge time would improve results

The study operator estimates that correcting these study factors would reduce the use of diesel fuel by approximately 65% - which would result in a significantly improved payback period.

It should be noted that the fuel savings calculated above assumes a linear relationship between fuel savings and distance travelled. In reality, fuel savings increase with distance traveled as a smaller percentage of the trip is spent warming and purging the vehicle and therefore a smaller percentage of diesel fuel is used per distance travelled during the trip. This also means that fuel savings are sub-optimal for short trips. The author of this report estimates no significant savings in diesel fuel for trips less than 5 km. Savings are high when the ratio of (kilometers driven to warm the engine) to (kilometers driven after the engine reaches operating temperature) is low.

9 Lessons Learned

Apart from the information obtained from researching the efficacy of using WVO as a fuel in Yukon conditions, the installer/operator of this vehicle learned the following lessons from the process:

9.1 Installation Cost

The installation was significantly more expensive than expected. The increase in installation cost was caused by both the mechanic's inexperience and the choice of vehicle for this conversion. Having gained experience in installing this first conversion, the mechanic estimates the cost of installing a second system would likely result in decrease in costs from 40-45%. Pick-up trucks and large trucks are reported to be easier for owners to install systems like these, and therefore much less expensive.

9.2 Purge Time

The time it takes to purge the fuel line of WVO before turning the vehicle off varies with the vehicle and installation, and part of the installation setup included setting the timing on the WVO purge cycle. The purge cycle in the study vehicle was very difficult to set; however, initially, it appeared that a 25 second purge time was sufficient.

After experiencing significant difficulties with the system, operation-induced cross-contamination of the diesel fuel and WVO was suspected. The purge time was increased to 1 ½ minutes, and the diesel fuel and filter were replaced. This change solved the problem.

During the summer following the commencement of the study, purging was done as follows:

- purge time was set at approximately 30 seconds;

- purging was done with the engine running at a minimum of 2000 rpm

Continuing with this protocol, the problem did not reoccur the subsequent winter. This process was found to purge the lines effectively. The purge cycle appears to require both sufficient time and sufficient fuel flow (via high RPM) to replace the WVO with diesel fuel.

9.3 WVO Storage

Initially, when the oil was being stored in unlined steel barrels, polymerization of the WVO occurred. The soft steel facilitated polymerization and when the polymerized WVO was used as a fuel for the study vehicle, the WVO filter clogged.

For long-term WVO storage, a sealed, non-reactive, impermeable container should be used. Ideally, the container should be completely filled to minimize contact with air. The 16 litre plastic "cubies" (used by many restaurants) appear to work well for storage as long as they are full, not in direct sunlight and only used for short periods. The plastic cubies are oxygen permeable and therefore facilitate polymerization over a long period of time; however, experience in Whitehorse and north of Anchorage, Alaska, indicates storage in cubies is not a significant problem in our cooler temperatures and low light conditions.

9.4 Heater Use During the Winter

When the heater temperature was turned up upon starting the engine (as most people do in the winter), it took three to four times as long for the engine to reach operating temperature. This prolonged the period during which diesel fuel was required prior to switching to WVO.

9.5 WVO Processing Plant

WVO must be kept warm in order for water and sediments to settle and to facilitate pumping and filtering of the oil. Substantial changes were required to keep the WVO processing shed adequately heated during the cold winter months.

A still and 2-micron filter and pump were used during the study for final dewatering and sediment removal. However, a commercially-available WVO centrifuge would likely be preferable for these tasks. It is likely that this would decrease the processing time and costs associated with replacing filters.

10 Conclusion

Based on the results of this study, it's clear that operating a vehicle which had been converted to use waste vegetable oil as its primary source of fuel is viable in the Yukon. The financial support of the Yukon Government's, Energy Solutions Centre has helped to provide an opportunity to demonstrate both the technical feasibility and the cost-savings advantages of these fuel-conversions in Yukon conditions.